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A dendrochronological reassessment of three Roman boats from Utrecht (the Netherlands): evidence of inland navigation between the lower-Scheldt region in *Gallia Belgica* and the *limes* of *Germania inferior*

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ABSTRACT

This study addresses the provenance of two Roman river barges and a Roman punt excavated along the *limes* of *Germania inferior* near the Dutch city of Utrecht (*De Meern 1*, *4* and *6*). To establish the geographical origin of these vessels, their tree-ring series are compared to 1452 dated oak (*Quercus robur/petraea*) growth patterns from Roman-period sites in the current Netherlands and Belgium. The strong resemblance to patterns of oak used in the *civitas Menapiorum* and the bordering region of *civitas Nerviorum* in *Gallia Belgica* indicates that the ships were built with oak from the lower-Scheldt region in present-day Flanders (north-western Belgium). Given the absence of Flemish oak in Roman land-based constructions along the Dutch *limes*, this provenance implies that the vessels were constructed in the lower-Scheldt region. The geographical location of the final wreck sites of *De Meern 1*, *4* and *6* points at inland-navigation between this region and the Rhine-based *limes* of *Germania inferior*.

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1. Introduction

The northern frontier of the Roman empire along the Rhine in the current Netherlands was established in AD 47 and abandoned around AD 270. Ships were used to transport troops and supplies to the frontier zone. This has resulted in many ship-archaeological finds in the central Netherlands dating to the Roman Period (e.g. Aarts, 2012; Blom and Vos, 2008; Bockius, 2002; Brouwers et al., 2013; De Groot and Morel, 2007; Haalebos, 1997; Jansma and Morel, 2007; de Weerd, 1988).

In 2003, the Cultural Heritage Agency of the Netherlands (RCE) and the municipality of Utrecht excavated a Roman river barge, which was termed *'De Meern 1'* after the district in which it was found (Fig. 1A; Jansma and Morel, 2007). Next in 2005, they performed a limited excavation of a second barge discovered at this location, *'De Meern 4'* (Fig. 1B; De Groot and Morel, 2007). Both barges are Zwammerdam-type flat-bottomed vessels, which were built from the bottom up and consist of bottom planks, L-shaped chine blocks and boards, held together with frames (Fig. 2). Partial remains of a smaller punt, *'De Meern 6'*, were excavated in this area in 2008 (Fig. 1C; Aarts, 2012).

In general, river barges from the Roman Period are 2.5–4 m wide and have a length of 25–40 m, with a width:length ratio of 1:7 to 1:10 (Jansma and Morel, 2007). The timbers of Zwammerdam-type barges are connected with iron nails. However *De Meern 4* differs in this respect, with dowel-and-tongue joints being used in addition to nails. The use of these joints has been interpreted as tracing back to the Roman construction of sea-faring ships in the Mediterranean region (De Groot and Morel, 2007). The construction of *De Meern 6* does not resemble that of other Roman ships excavated in the Netherlands (Dallmeijer and Morel, 2012). Based on comparisons with more recent ship types it has been concluded that *De Meern 6* belongs to the typological 'family' of punts (Dallmeijer and Morel, 2012).

Dendrochronology has shown that the oaks providing the timbers of *De Meern 4* were felled around AD 100 and those of *De*

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Fig. 1. Field observations of *De Meern 1, 4* and *6*; A: *De Meern 1* during its excavation in 2003 (from: Jansma and Morel, 2007); B: limited excavation of *De Meern 4* in 2005, filmed at that time by Time Team (Channel 4, UK; from: De Groot and Morel, 2007); C: the excavation of *De Meern 6* in 2008 (from: Dallmeijer and Morel, 2012).

Meern 1 around AD 148 (Jansma, 2007a,b). The single timber of *De Meern 6* that could be dated, was cut from a tree felled after AD 158 (Dallmeijer and Morel, 2012). Based on dendrochronological matches with available tree-ring reference chronologies, at that time it was concluded that the timbers of these ships were derived from trees that grew in the Netherlands (Jansma, 2007a,b; Dallmeijer and Morel, 2012). Consequently, the interpretation was that all three ships had been built locally.

Recently the accuracy of dendrochronological wood provenancing in the Low Countries has improved considerably through the development of the 'Digital Collaboratory for Cultural Dendrochronology' (DCCD), an international data infrastructure for

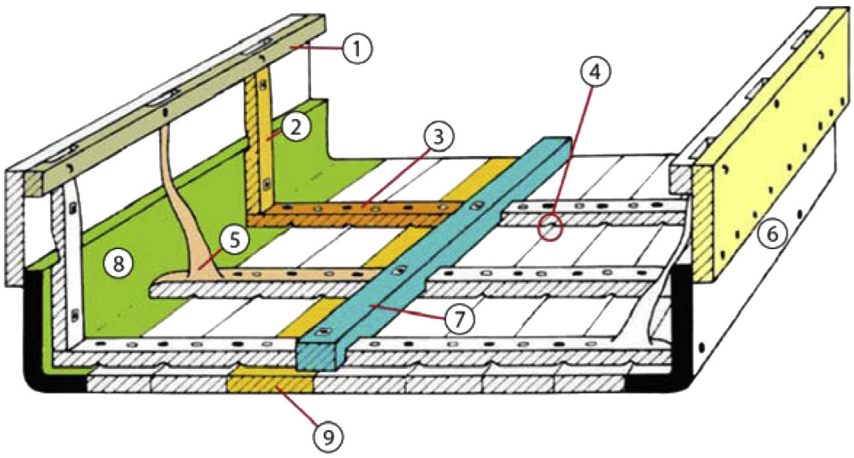

Fig. 2. Schematic cross section of the Zwammerdam-type river barge (after: De Weerd, 1988, 297); 1 = fender; 2 = futtock; 3 = frame; 4 = limber hole/watercourse; 5 = frame and knee; 6 = board; 7 = keelson; 8 = L-shaped chine block; 9 = bottom plank.

dendroarchaeology (Jansma et al., 2012a). The DCCD includes a searchable repository at http://dendro.dans.knaw.nl containing all tree-ring data and research results gathered in the Netherlands since the 1960's as well as, among others, extensive datasets from Belgium (Jansma, 2013). Triggered by the new research possibilities the provenance of Roman timbers used in the Low Countries is currently being reinvestigated. The study presented here is focussed at reassessing the origin of the oak timbers (*Quercus robur/petraea*) of *De Meern 1*, *4* and *6*.

2. Materials

2.1. De Meern 1

De Meern 1 measures 25 by 2.7 m and was active between *c*. AD 150 and 200, first in a military context and during its final years owned by a carpenter, possibly a veteran active along the *limes* (Jansma and Morel, 2007). This vessel contained a cabin, a cooking area and a hold (Fig. 1A). Its hull was built with oak. However, in the cabin other wood species were used besides oak for furnishing purposes, such as alder (*Alnus* sp.), beech (*Fagus sylvatica*), ash (*Fraxinus excelsior*) and maple (*Acer* sp.) for furniture, and silver fir (*Abies alba*) for some of the floor planks (Brinkkemper et al., 2007). These other species are excluded from the present analyses.

The dendrochronological study of *De Meern 1* involved 18 oak elements (Table 1, Jansma, 2007b). The structural timbers are its four bottom planks (DMN10031, DMN10041, DMN10050 and DMN10061), two L-shaped chine blocks (DMN10021 and DMN100070) and two fenders (DMN10010 and DMN10081). These timbers were sampled *c*. 12.5 m from the stern, where the hull had been sawn through in two pieces preceding its conservation (Jansma, 2007b). The non-structural oak elements in the dataset are two cabin doors (DMN1KD10 and DMN1KD20), two floor planks from the ship's cabin (DMN10301 and DMN10310), two planks that were part of the shipper's bed (DMN1025 and DMN10341), one plank that most likely was part of the bed (DMN10331), a plank from the cabin that could be ascribed to either the bed or the floor (DMN10351), and two possible repair planks (DMN10360 and DMN10370). During the analyses the non-structural timbers were treated in a non-destructive manner, with tree-ring measurements being made along existing breaks in the material (Jansma, 2007b).

The four bottom planks of *De Meern 1* are derived from a single tree, as are the undated L-shaped chine blocks (Fig. 3A and B). Although at the time it was concluded that both fenders also were derived from a single tree (Jansma, 2007b), this cannot be confirmed given a somewhat low similarity between the central parts of their tree-ring series (Fig. 3C). Both cabin doors were constructed from a single tree as well (Fig. 3D).

Prior to the analyses, tree-ring series representing the same tree were averaged into single-tree series (TS), resulting in derived series DMN1_BP_T representing the bottom planks, DMN1_2_7_T representing the L-shaped chine blocks and DMN1_KD_T representing the cabin doors (Table 1). This resulted in a *De Meern 1* data set of 13 TS, each representing an individual tree.

2.2. De Meern 4

The exact dimensions of *De Meern 4* are unknown since only a small part of this vessel has been excavated (Fig. 1B). Based on field observations the size of this vessel is estimated at *c*. 27 by 4 m (De Groot and Morel, 2007). The dendrochronological study involved 14 structural oak timbers: 7 bottom planks (tree-ring series DMN40031, DMN40051, DMN40061, DMN40121, DMN40131, DMN40140 and DMN40150), 2 L-shaped chine blocks (DMN40010 and DMN40160), two fenders (DMN40041 and DMN40111), two boards (DMN40021 and DMN40091) and an element placed between a board and fender (DMN40101; Jansma, 2007a, Table 1). The construction of *De Meern 4* at the studied segment did not have a symmetrical layout along the length axis of the vessel. Instead, planks from specific trees were used at random positions in the hull (Jansma, 2007a). The timbers had been derived from oaks growing in an uneven-aged forest, with ring counts varying from 69 to 282 (Jansma, 2007a).

Two sets of bottom planks of *De Meern 4* were originally assigned to a single tree each (Jansma, 2007a). These are respectively DMN40051 and DMN40140 (Fig. 3E), and DMN40061 and DMN40150 (Fig. 3F). Based on close visual inspection we decided against treating DMN40051 and DMN40140 as representing the same tree. Both other series were averaged into TS DMN4_6_15_T. This resulted in a *De Meern 4* data set of 13 TS (Table 1).

2.3. De Meern 6

The dimensions of *De Meern 6* are estimated at 9 by 1 m based on a well-preserved lancet-shaped bottom plank, a board plank, parts of five frames and evidence of a stem or stern post (Dallmeijer and Morel, 2012, Fig. 1C). The dendrochronological study of *De Meern 6* involved the floor and board planks (DMN60010 and DMN60020; Dallmeijer and Morel, 2012). Only the board plank

Table 1
Dendrochronological data from *De Meern 1*, *De Meern 4* and *De Meern 6*.

Ship	Element(s)	Find number	DCCD project number	DCCD series identifier	First year	Last year	Nr. of sapwood rings
De Meern 1	Bottom planks (4)	GA2, GB2, GC2, GD3	P:2003082	DMN1_BP_T: average of measurement series DMN10031, DMN10041, DMN10050 and DMN10061	11 BC	AD 138	10
	L-shaped chine blocks (2)	SB, BB	P:2003082	DMN1_2_7_T: average of DMN10021 and DMN10070	Undated		2
	Fenders (2)	SB, BB	P:2003082	DMN10010	14 BC	AD 101	0
				DMN10081	AD 6	AD 123	0
	Cabin doors (2)	LH-34, LH-35	P:2004023	DMN1_KD_T: average of measurement series DMN1KD10 and DMN1KD20	43 BC	AD 119	0
	Bed plank	DMN1-239	P:2004070	DMN10251	46 BC	AD 138	0
	Cabin floor plank	DMN1-283	P:2004095	DMN10301	79 BC	AD 52	0
	Cabin floor plank	DMN1-282	P:2004095	DMN10310	69 BC	AD 118	0
	Bed plank (likely)	DMN1-213b	P:2004095	DMN10331	63 BC	8 BC	0
	Bed plank	DMN1-228	P:2004095	DMN10341	AD 20	AD 137	0
	Bed plank or cabin floor plank	DMN1-245	P:2004095	DMN10351	Undated		6
	Plank, possible repair	G1A/BB	P:2005071	DMN10360	AD 52	AD 137	5
	Plank, possible repair	G3A/SB	P:2005071	DMN10370	AD 22	AD 113	0
De Meern 4	Bottom plank	GC	P:2005050	DMN40051	113 BC	AD 52	0
	Bottom planks (2)	GB, GD	P:2005050	DMN4_6_15_T	119 BC	AD 50	0
	Bottom plank	GA	P:2005050	DMN40031	118 BC	AD 71	0
	Bottom plank	GF	P:2005050	DMN40121	AD 3	AD 85	9
	Bottom plank	GG	P:2005050	DMN40131	174 BC	AD 24	0
	Bottom plank	GE	P:2005050	DMN40140	178 BC	AD 37	0
	L-shaped chine block	Kbb	P:2005050	DMN40010	156 BC	AD 52	0
	L-shaped chine block	Ksb	P:2005050	DMN40160	130 BC	AD 77	1
	Fender	BBbb	P:2005050	DMN40041	Undated		0
	Fender	BBsb	P:2005050	DMN40111			0
	Board	BHbb	P:2005050	DMN40022	AD 20	AD 74	0
	Board	BHsb	P:2005050	DMN40091	AD 35	AD 87	3
	Element between board and fender	Bsb	P:2005050	DMN40101	22 BC	AD 75	0
De Meern 6	Bottom plank	–	P:2010064	DMN600020	AD 44	AD 145	0

could be dated and therefore in this study *De Meern 6* is represented by a single TS only (Table 1).

2.4. Reference data

We reassessed the provenance of *De Meern 1*, *4* and *6* (33 dated timbers, 27 TS) using 1452 oak tree-ring series from the Low Countries dating to the Roman period (Fig. 4). These reference data result from 186 dendroarchaeological and 24 dendro-ecological studies conducted in the Netherlands and Flanders (northern Belgium) between 1985 and December 2012 (Supplementary material; Fig. 4).

3. Method

3.1. Data retrieval

The reference data were downloaded from the DCCD at http://dendro.dans.knaw.nl together with their research documentation. The measurement series were ingested into software library PAST4 (Knibbe, 2008), which was used for dendrochronological comparisons. The descriptive and interpretative metadata were imported into tree-ring database TRiDaBASE (Jansma et al., 2012b), which we used for administrating geographical provenance results and further interactions with the DCCD repository.

3.2. Data classification

The dendrochronological data was classified according to the types of objects and the associated degree of organization they represent (Supplementary material). The following categories were attributed:

- *High degree of organization*: planned infrastructural construction works such as bridges, canals, fortresses, harbours, roads and transport vessels;
- *High to moderate degree of organization*: possibly planned construction works such as temples, *villae* (i.e. large agricultural settlements) and *vici* (i.e. Roman trade and production centres);
- *Moderate degree of organization*: locally organized construction works such as (parts of) rural settlements (e.g. water wells, farm houses);
- *No organization*: natural forests and woodlands (i.e., naturally-deposited oak trunks recovered in former peat areas and river-sedimentation layers).

The rationale behind this approach is the expectation that Roman strategic constructions could well have included timbers harvested in regions at a distance from the construction sites (e.g. Domínguez-Delmás et al., 2014), whereas rural settlements can be expected to contain a larger amount of locally-derived timber. We used a separate class for naturally-deposited tree trunks, since their growth patterns can be used as a reference for distinguishing locally-harvested from exogenous oak.

3.3. Dendrochronological comparisons

The series were compared using standard dendrochronological cross-dating statistics: Student's *t*-values (t_H, based on Pearson's cross-correlation coefficients (r) between measurement series

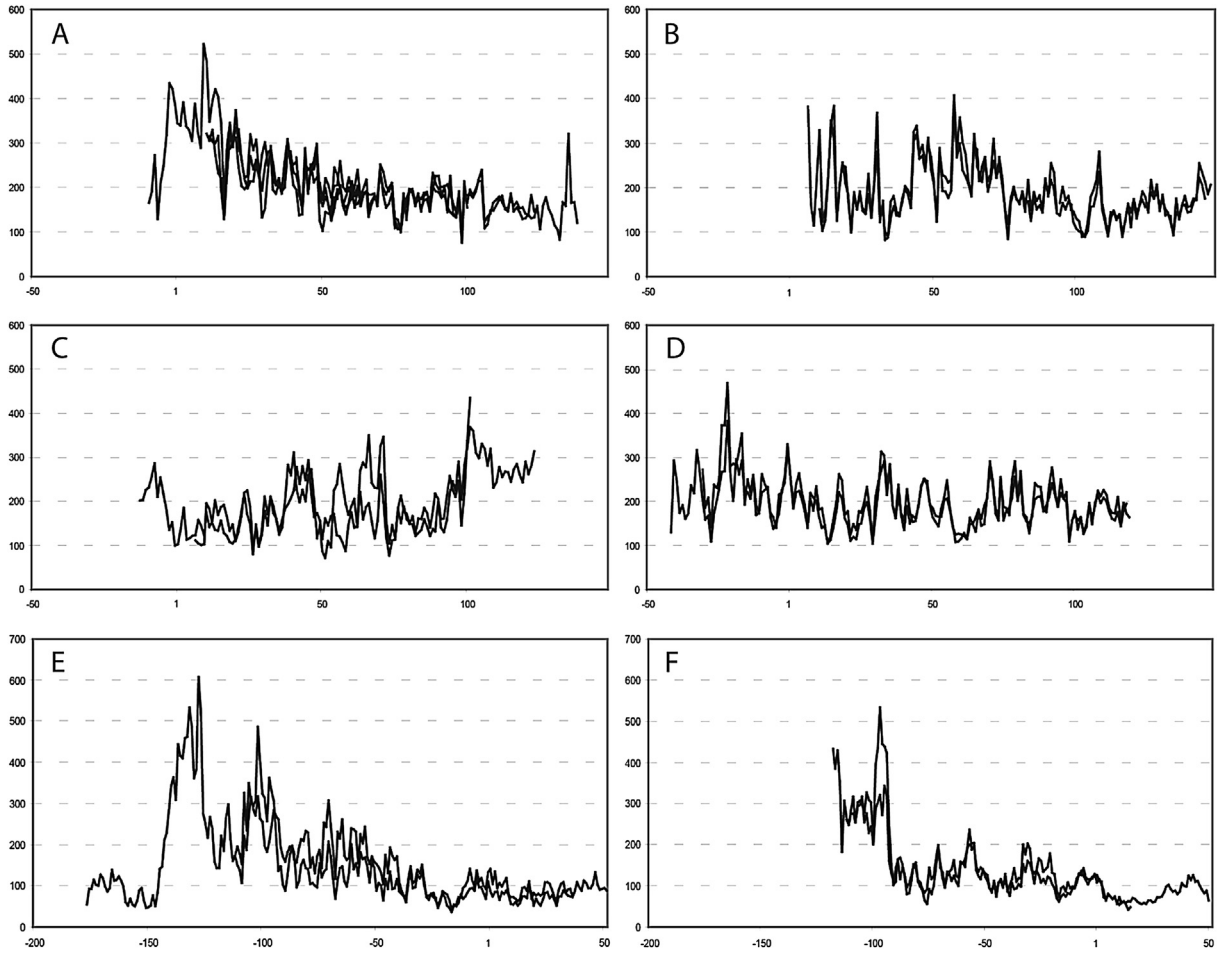

Fig. 3. Visual comparisons between selected series. A: four bottom planks *De Meern 1*; B: two L-shaped chine blocks *De Meern 1*; C: two fenders *De Meern 1*; and D: two cabin doors *De Meern 1*; E: two bottom planks *De Meern 4*; F: two bottom planks *De Meern 4*. The *X*-axis shows time, with 50-yr intervals between consecutive markers.

detrended using a logarithmic transformation (Hollstein, 1980)) and the percentage of Parallel Variation (*%PV*) with its significance level *p* (Eckstein and Bauch, 1969).

We refrained from compiling object and site chronologies, since this approach might involuntary introduce bias regarding geographical wood provenance. For instance, a mix of local and non-local timber could be represented on a particular site, which would result in an average chronology with a mixed signal that cannot be used for determining wood provenance. Also, this approach could lead to the inclusion of relatively complacent series in chronologies, which potentially lowers the location-dependent signal. Therefore we assume that all timbers could have been moved from their original growth location and compared all individual growth patterns regardless of their geographical and archaeological context.

Patterns showing strong similarities with individual patterns of *De Meern 1*, *4* and *6* were grouped together with these patterns into 'timber groups' (TGs). To this end we repeated the following steps: (a) averaging strongly-matching series into a rudimentary TG; (b) comparing its average chronology against the ungrouped series; (c) selecting new series for inclusion into the provisional TG; (d) verifying that newly selected series do not match strongly with remaining ungrouped series; (e) if necessary based on (d): removing series from the new selection; (f) creating a new group average; (g) verifying the average correlation between the series in the extended TG (it should not become weaker); (f) if necessary based on (e): removing series that weaken the common signal.

During these classifications we used $t_H \geq 6.8$ and $\%PV \geq 68\%$ as indicative of a strong dendrochronological match based on our experience with timbers and palaeo-vegetation remains excavated in the Low Countries. In addition we visually guarded the similarity of the patterns with emphasis on the lower-frequency variations (multi-year trends of decreasing and increasing ring width), since such similarities cannot be detected directly through overall values for t_H and *%PV*. Series representing the same tree were identified and averaged to ensure that each series in the resulting TGs represents an individual tree. As a final step the individual series were detrended using Cofecha (Holmes, 1983), after which the final content of each TG was established based on cross-correlation coefficients (r) between single series and the average of all other series in this TG using a threshold significance level of $p < 0.0001$.

After grouping the series, TS of *De Meern 1*, *4* and *6* that could not be assigned to a TG were compared to all other series ($n = 1452 + 27 - 1 = 1478$). Based on the strongest matches we deduced the hypothetical provenance of these ungrouped timbers.

3.4. Chronological distribution of felling dates

The chronological composition of the TGs was determined exclusively from series representing timbers that contain sapwood, as in these cases felling dates can be estimated accurately. Series from timbers that lack sapwood only yield *terminus post quem* dates, which is too unspecific for the purposes of this study. Estimated felling dates and felling-date ranges were mostly based on

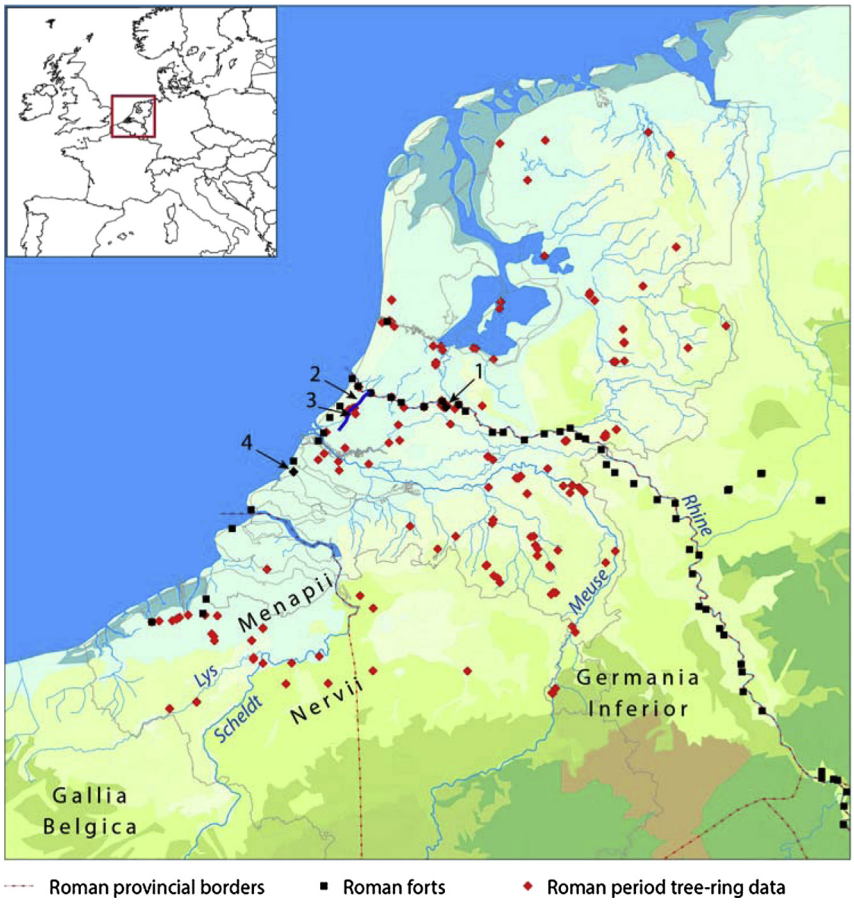

Fig. 4. Geographical distribution of Roman-period sites (soil map: after Vos et al., 2011); 1 = find location of *De Meern 1*, *4* and *6*; 2 = *Fossa Corbulonis*; 3 = *Forum Hadriani*; 4 = Roman harbour at Goedereede-Oude Oostdijk.

sapwood estimates by the authors of the data and laid down in the research reports available through the DCCD. In case of missing reports, we deduced felling dates using calculations presented by Jansma (2007b).

3.5. Spatial interpretation

After assigning the timbers of *De Meern 1*, *4* and *6* to TGs, their provenance was inferred from the TG's organization level and spatial distribution. Here we reasoned that if a TG includes object types requiring a moderate organization level and those objects originate from archaeological sites located in a region where oak occurred naturally, it follows that the timbers included in this group were harvested locally. On the other hand, if a TG mostly represents planned structures built with timber brought in from more remote areas (e.g. the Ardennes; Dominguez-Delmás et al., 2014), it follows that all timbers in this group must be from this more remote area.

For a more detailed spatial interpretation, an expectation map of oak was created for NW-Europe. This map combines information about Roman-period topography, geomorphology and soil type with the ecological demands of pedunculate and sessile oak (*Q. robur/petraea*), and in this manner estimates the natural geographical distribution of these tree species during the Roman period.

a. *Topography*: regional topography was reconstructed by combining the following datasets: (*i*) The European Landscape Map (dataset LANMAP2, Alterra (2007), Wageningen University, NL); (*ii*) Willemse and Boshoven (2011); (*iii*) De Bethune (1968); (*iv*) soil regions of the Federal Republic of Germany (dataset of the Federal Institute for Geosciences and Natural Resources (2010), Federal Ministry of Economics and Technology, D); (v) Klostermann (1992); (*vi*) outline maps of the geology of the federal states of Hessen and Schleswig-Holstein (D); (*vii*) Voss et al. (2011); (*vii*) Van Dinter (2013), dataset Lower Rhine; (*ix*) Atlas of the Flemish landscape, traditional landscapes in the Flemish region (dataset Ghent University (2002), BE; De Clercq, 2009).
b. *Geomorphology and soil type*: these were reconstructed by adapting the LANMAP2 dataset to the palaeo-landscape data of AD 100 defined by Vos et al. (2011).
c. *Forest cover* (*Q. robur/petraea*): we estimated the geographical distribution of pedunculate and sessile oak in NW Europe by combining their distribution ranges as defined by Ducousso and Bordacs (2004) with the results of a–b.

To allow assessments of local/regional accessibility of timber we added spatial information about the Roman road system (Talbert, 2000; Dhaeze, 2011) to the expectation map.

4. Results

The comparison of the ships TS (27) with the DCCD-based reference dataset (1452) resulted in two timber groups, that together comprise 119 TS (8.2% of the dataset).

Table 2
Content of Roman timber group TG(A).

DCCD series identifier	Find location	DCCD project code	Structure	Element type	First year	Last year	Felling date[a]
BAM30011	Brugge (SAM306)	P:2002124	Water well	Unknown	156 BC	9 BC	After AD 12 ± 6
BAR00031	Brugge Refuge	P:1997010	Water well	Plank	95 BC	AD 66	In AD 85 ± 8
BAR00041				Plank	168 BC	37 BC	
BAR00091				Plank	168 BC	43 BC	
BAR00111				Plank	70 BC	AD 57	
BHC00110	Borssele Ellewoutsdijk	P:2000014	House	Pile	39 BC	AD 56	In AD 88–131 (several
BHC00320		P:2002083	House	Pile	63 BC	AD 46	building phases)
BHC00340			House	Pile	AD 9	AD 62	
BHC00370			House	Pile	58 BC	AD 13	
BHC00380			House	Pile	63 BC	AD 10	
BHC00420			House	Pile	60 BC	AD 58	
BHC00511		P:2003010	House	Pile	AD 9	AD 88	
BHC00521			House	Pile	95 BC	AD 40	
BHC00561			House	Pile	1 BC	AD 78	
BHC00591			House	Pile	8 BC	AD 88	
BHC00651			House	Pile	25 BC	AD 81	
BHC00660			House	Pile	96 BC	AD 130	
BHC00671			House	Pile	65 BC	AD 80	
BHC00701			House	Pile	7 BC	AD 81	
BHC00711			House	Pile	AD 23	AD 81	
BHC00721			House	Pile	2 BC	AD 73	
BHC00731			House	Pile	51 BC	AD 91	
BHC00741			House	Pile	AD 2	AD 71	
BHC00771			House	Pile	42 BC	AD 90	
BHC00781			House	Pile	AD 4	AD 84	
BHC00811			House	Pile	81 BC	AD 74	
BHC00821			House	Pile	2 BC	AD 70	
BHC00831_851_881_T			House	Pile	96 BC	AD 57	
BHC00841			House	Pile	AD 25	AD 110	
BJG00021	Jabbeke	P:2003050	Water well	Unknown	170 BC	7 BC	In AD 149 ± 8
BJV00040	Varsenare d'Hooghe Noene	P:2001014	Water well	Unknown	163 BC	46 BC	After BC 26 ± 6
BSK00011	Brugge Sint Kruis	P:2001021	Water well	Unknown	46 BC	AD 55	After 75 ± 6
BUWP10.17	Burst	2010_P11	Water well	Small beam	AD 25	AD 108	In AD 115–140 (single
BUWP10.21				Small beam	AD 36	AD 110	building phase)
DA-AH-01m	Damme Antwerpse	1998_P1	Water well	Plank	68 BC	AD 82	After AD 112 ± 6
DA-AH-15am	Heirweg			Plank	AD 25	AD 89	
DEHO09.19	Dendermonde	2010_P12	Water well	Plank	82 BC	AD 63	In AD 80–100 (single
DEHO09.21	Hoogveld			Plank	87 BC	AD 64	building phase)
DEHO09.22				Plank	80 BC	AD 69	
DMN10010	Utrecht De Meern	P:2003082	Ship De Meern 1,	Plank	14 BC	AD 101	In AD 148 ± 6
DMN10081			fenders	Plank	AD 6	AD 123	
DMN1_KD_T		P:2004023	Ship De Meern 1, cabin doors	Planks	43 BC	AD 119	After AD 145 ± 8
DMN10341		P:2004095	Ship De Meern 1, bed	Plank	AD 20	AD 137	After AD 157 ± 6
DMN10360		P:2005071	Ship De Meern 1, possible repair	Plank	AD 52	AD 137	After AD 156 ± 6
DMN10370		P:2005071	Ship De Meern 1, possible repair	Plank	AD 22	AD 113	After AD 132 ± 6
DMN40010		P:2005050	Ship De Meern 4, hull	L-shaped chine block	156 BC	AD 52	In AD 100 ± 2
DMN40051				Plank	113 BC	AD 52	
DMN40121				Plank	AD 3	AD 85	
DMN40131				Plank	174 BC	AD 24	
DMN40160				L-shaped chine block	130 BC	AD 77	
DMN60020		P:2010064	Ship De Meern 6	Plank	AD 44	AD 145	After AD 158
EL-20-M	Elewijt Waverse Baan	2003_P4	Water well near *vicus*	Planks (3)	90 BC	AD 100	After AD 126 ± 8
EVKS08.31	Evergem Koolstraat	2010_P13	Water well	Plank	AD 35	AD 195	After AD 212
EVKS08.33				Plank	AD 40	AD 200	
GNT.SDW1.H10	Gent (Flanders	2009_P5	Water well	Plank	61 BC	AD 78	In AD 99–124 (single
GNT.SDW1.H22_ H26_H30_H32_ H40_H42_H50_H52_T	expo, 2008)			Planks	56 BC	AD 88	building phase)
GNT.SDW1.H51				Plank	22 BC	AD 75	
GNT.SDW2.H11_H12_ H14_H16_H18_H25_H6_T			Water well	Planks	147 BC	AD 68	In AD 76–101 (single building phase)
GNT.SDW2.H19				Plank	96 BC	AD 59	
GNT.SDW2.H5				Plank	158 BC	AD 57	
HA12.DEN.23	Harelbeke Dennenlaan	2012_P1	Water well near *vicus*	Plank	80 BC	AD 93	After AD 131

Table 2 (*continued*)

DCCD series identifier	Find location	DCCD project code	Structure	Element type	First year	Last year	Felling date[a]
KL.wp01.12	Evergem Kluizendok	2009_P6	Water well	Plank	AD 10	AD 123	After AD 135
KL.wp02.07			Water well	Plank	49 BC	AD 37	After AD 46
KL.wp22.02			Water well	Plank	41 BC	AD 122	In AD 202–223 (single building phase)
Knes-AQb-P30A	Knesselare	2006_P3	Water well	Plank	124 BC	9 BC	In 2 BC – AD 8 (single building phase)
MB-01b_xx_T	Merelbeke	2003_P6	Water well	Plank	18 BC	AD 59	After AD 155 ± 6
MB-Z1				Plank	86 BC	AD 51	
MB-ZW9_ZW8_T				Plank	13 BC	AD 130	
MEK.07.N7	Menen Korte	2007_P5	Water well	Plank	AD 3	AD 93	In AD 116–132 (single building phase)
MEK.07.O3	Waagstraat			Plank	73 BC	AD 116	
MEK.07.O6				Plank	1 BC	AD 71	
MEK.07.W1				Plank	89 BC	AD 96	
MEK.07.W6				Plank	103 BC	AD 47	
MEK.07.W7				Plank	55 BC	AD 63	
VFH00380	Leiden Voorburg	P:2008057	Harbour	Pile	AD 12	AD 129	In ca. AD 160

[a] Felling dates are given in the right-hand column. The term 'in' describes an exact, sapwood-based felling date or felling-date range; the term 'after' indicates a *terminus post quem* date.

The first timber group, TG(A), contains the 12 TS of *De Meern 1*, *4* and *6* that could be assigned to a TG (Table 2). In addition this group is comprised of timbers from moderate organization-level structures centering in *civitas Menapiorum* (current Flanders, BE: 36 TS from water wells; Zeeland (Borssele), NL: 24 TS from farm houses), 2 TS from water wells from sites in this region described as Roman *vici* (Harelbeke and Elewijt), and a single TS from the more northern high organization-level site *Forum Hadriani* (this Roman town's harbour). The 75 TS in this group cover a period of 374 years, from 174 BC to AD 200. The strength of the match between the Utrecht ships and the mainly Flemish material becomes especially clear when we divide TG(A) into subgroups TG(A)_U (the Utrecht ships) and TG(A)_F (the Flemish/Zeelandish data) and compare these against each other (Fig. 5). The similarity between their respective chronologies is exceptionally strong and expressed by $t_H = 15.6$ and $\%PV = 73.7$, with an overlap of 315 years.

The spatial distribution of TG(A) is centred in Flanders, near the confluence of the rivers Lys and Scheldt (Fig. 6). The Flemish structures included in TG(A) were built between *c.* AD 2 and 213 (Fig. 7; Table 2), for the largest part predating the interval of marked Roman military presence that in this region started around AD 170 (Dhaeze, 2011; De Clercq, 2009).

The second timber group, TG(B), contains a bed plank and a cabin-floor plank of *De Meern 1*. In addition, it represents piles and planks from high and high to moderate level organization structures situated along the Dutch *limes* and the Dutch North-Sea coast (Fig. 6; Table 3): remains of a temple and *vicus* at Elst (10 TS), a fortress at Valkenburg (3 TS), and the Roman town *Forum Hadriani* (Leidschendam Voorburg; 29 TS). The 44 tree-ring series in this group span 326 years, covering the interval 121 BC–AD 205. The distribution of felling dates shows that the timbers in TG(B) were felled during the first decades of the 3rd century AD (AD 205–227; Table 3).

Ungrouped TS DMN10310, DMN4_6_15_T, DMN400022, DMN40031, DMN40091, DMN40101 and DMN40140 match best against individual TS from TG(A) or against other ungrouped ships timbers that in turn match best against components of TG(A) (Table 4). These timbers therefore most likely were derived from the growth region of TG(A). The provenance of two TS could not be determined (DMN1_BP_T and DMN100331).

5. Interpretation and discussion

5.1. Provenance of De Meern 1, 4 and 6

Most ship timbers included in TG(A) are structural elements, *De Meern 1* being represented by two fenders, *De Meern 4* by four bottom planks and two L-shaped chine blocks, and *De Meern 6* by a

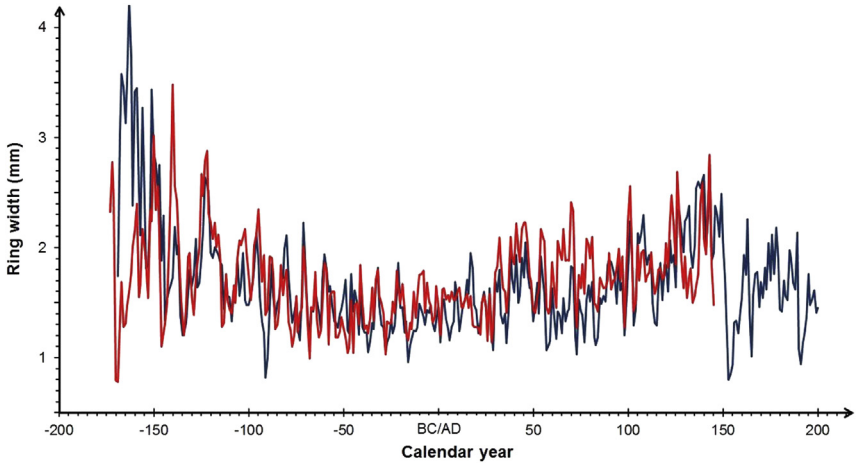

Fig. 5. Visual match between chronologies TG(A)_U (red) and TG(A)_F (blue). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

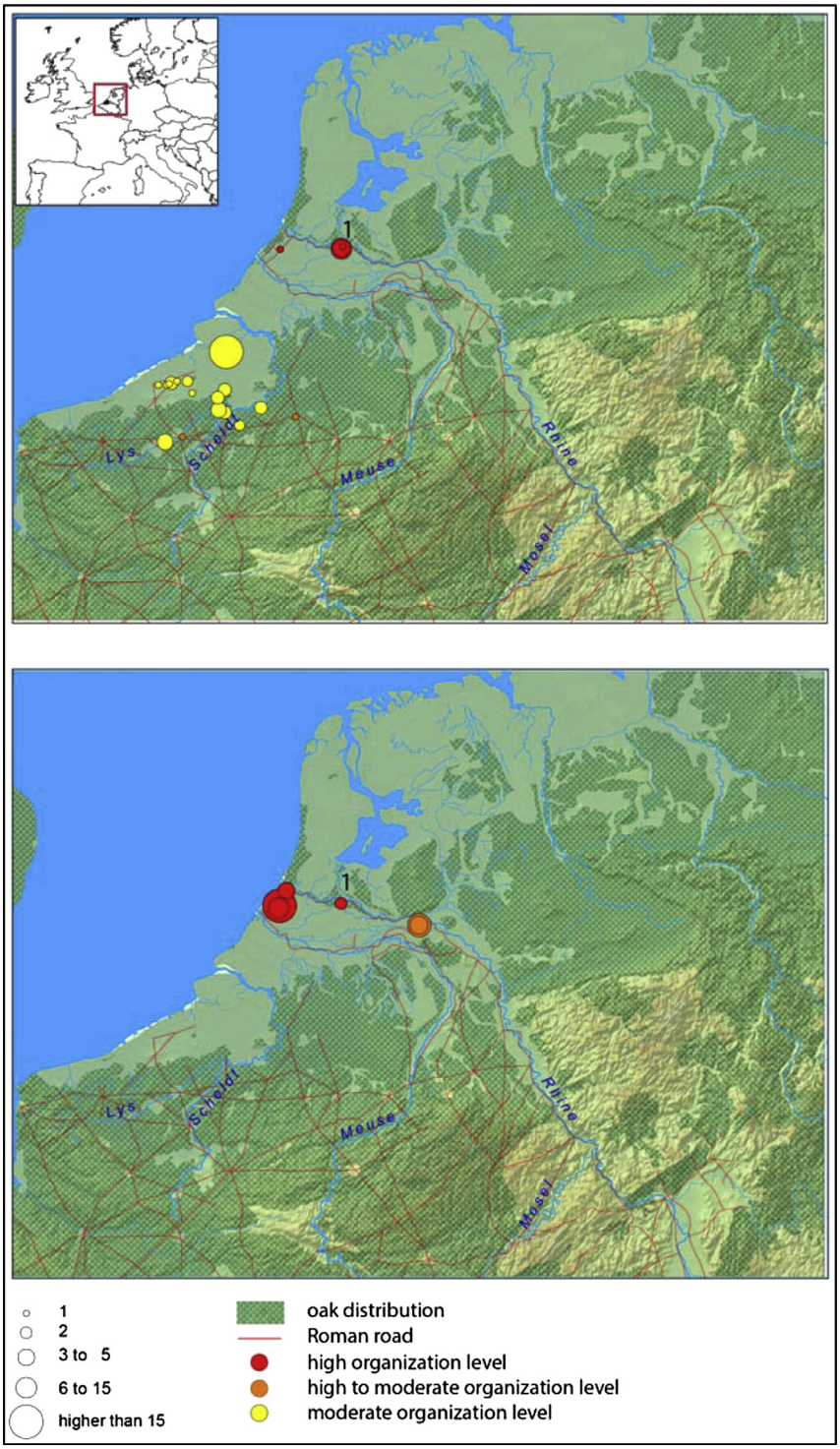

Fig. 6. Geographical distribution of timbers included in TG(A) (upper part) and TG(B) (lower part). The size of the markers indicates the number of TS. 1 = find location of *De Meern 1, 4* and *6*.

bottom plank (Table 2). These elements cannot have been replaced at a later stage and therefore must belong to the wood assemblages used for their initial construction.

The timbers constituting TG(A) most likely were harvested in the lower-Scheldt region of the *civitas Menapiorum* and the bordering region of *civitas Nerviorum*, since (a) they mainly are derived from rural settlements in this area which most likely relied on nearby wood sources, (b) they mainly date before AD 170, hence before the interval of marked military influence and infrastructural activity in this region (Dhaeze, 2011; De Clercq, 2009), and (c) archaeological and palaeo-ecological evidence as well as written sources indicate that during the Roman period many forests occurred in this region (De Clercq, 2009, 2011). Regretfully we were unable to test the hypothesis of a more southern provenance of the timber, since the reference data set does not contain tree-ring series from timbers excavated in north-western France. Nonetheless,

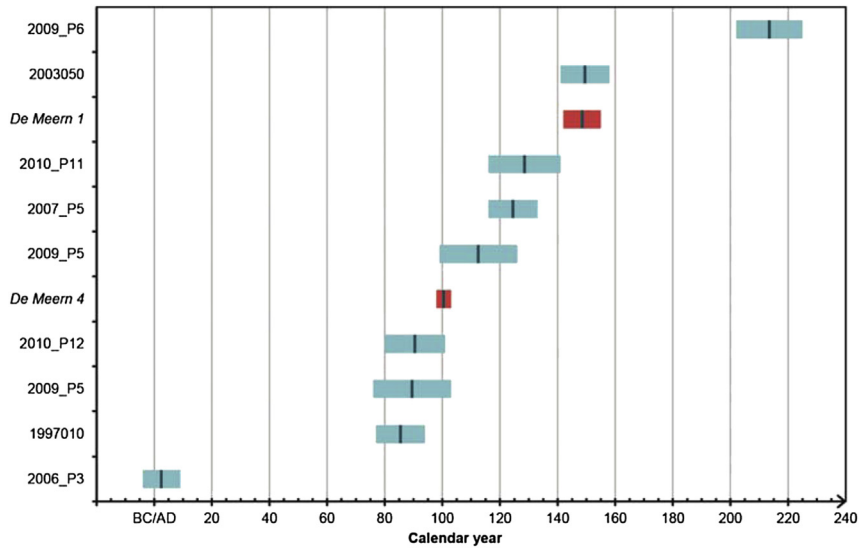

Fig. 7. Chronological distribution of Flemish sites in TG(A). Squares: estimated felling-date ranges based on the number of sapwood rings (also see Table 2). The felling dates of *De Meern 1* and *4* are marked in red. *De Meern 6* is excluded from this graph due to lacking sapwood. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the dendrochronological match between the average chronology of the ship-timber group TG(A)_U and TG(A)_F composed of timbers from archaeological sites in the lower-Scheldt region of the *civitas Menapiorum* and the neighbouring area of *civitas Nerviorum* is exceptionally strong (Fig. 5). It would be highly surprising if this match would become significantly stronger by the inclusion in TG(A)_F of tree-ring series from north-western France.

De Meern 1, *4* and *6* have been uncovered along the *limes* near Utrecht. Although the reference dataset represents a considerable amount of oak timbers from Roman-period land-based structures in the *limes* region ($n = 210$; Supplementary material), our results indicate that none of this material is Flemish (Fig. 6). Given the substantial size of the reference dataset, which we assume to be representative of actual Roman wood use along the *limes* of *Germania inferior*, this implies that no direct connection existed with the Scheldt region in terms of timber supply. It therefore becomes highly unlikely that the Romans transported unworked oak from Flanders to the Dutch *limes* for ship-building purposes. The implication is that *De Meern 1*, *4* and *6* were not constructed along the *limes* of *Germania inferior*. They most likely were built in the lower-Scheldt region of *Gallia Belgica*.

5.2. Navigating from Gallia Belgica to northern Germania inferior

Flat-bottomed river barges were unsuited for navigating the North Sea since they did not have a keel, and therefore would not be able to withstand the swells. The provenance of *De Meern 1* and *4* in *Gallia Belgica* therefore indicates that these vessels navigated to the North using inland water connections between the Scheldt and Meuse and between the Meuse and Old Rhine. The same holds for the much smaller punt *De Meern 6*.

Recent archaeological evidence shows that the Scheldt may have been connected to the Meuse through a combination of natural inlets and a dug canal (Van der Kroft et al., 2006; De Bruin et al., 2012). This would certainly explain the presence of a Roman harbour in the centre of this coastal range at Goedereede-Oude Oostdijk (De Bruin et al., 2012, Fig. 4). North of this possible waterway, the Meuse and Old Rhine were connected through the *Fossa Corbulonis*, which was dug in *c*. AD 50 under command of Gnaius Domitius Corbulo (De Kort and Raczynski-Henk, 2014). The Roman town of *Forum Hadriani* was located along this canal (Fig. 4). Major building campaigns at *Forum Hadriani*'s harbour in *c*. AD 160 and 205 (Domínguez-Delmás et al., 2014) indicate that this or a successive canal may have functioned at least until the first decade of the third century. The use of a wooden pile with a provenance in *Gallia Belgica* in the harbour of *Forum Hadriani* around AD 160 (Fig. 6; Table 2) confirms the connection between the Scheldt and the *Fossa Corbulonis*.

There are independent archaeological indications that *Gallia Belgica* economically was linked to the Dutch *limes*. For example *Woerden 1*, a ship excavated in 1978 along the *limes* near the army camp of Woerden, carried a cargo of emmer wheat which given the presence of specific weeds (i.e. *Orlaya grandiflora*) probably was cultivated in the southern loess landscapes in *Gallia Belgica* (Pals and Hakbijl, 1992; Roymans and Derks, 2011). It is also worth mentioning that cooking pots were found aboard *Woerden 1* that were identified as derived from Flanders (Haalebos, 1986). Contacts by ship between Flanders/Northern France and the *limes* furthermore have been demonstrated by the find in Nijmegen of an altar from M. Liberius Victor, a Nervian merchant in cereals (*frumentarius*; see Roymans and Derks, 2011: 19). These archaeological indications do not provide an exclusive link to the lower Scheldt-region. However, our results confirm this economic connection, for the first time showing that major transport vessels excavated along the Dutch *limes* in Utrecht-De Meern originated in the lower-Scheldt region of *Gallia Belgica*.

5.3. Life span and action radius of De Meern 1

The wreck of *De Meern 1* includes non-structural oak elements that most likely were added after its initial construction (i.e. bed planks, floor planks, repair planks). This allows us to assess the life span and action radius of this vessel in more detail.

The cabin doors, a bed plank and two repair planks of *De Meern 1* originate in *Gallia Belgica* (Table 2). Given the lack of Flemish timber along the Dutch *limes* (see 5.1) it is unlikely that these additions were made near the final wreck site. The geographical distribution of TG(A) indicates that *De Meern 1* most likely navigated the Scheldt-Lys region when these additions were made.

Domínguez-Delmás et al. (2014) have shown that timbers from *Forum Hadriani*'s harbour with felling dates around AD 205 were derived from the Ardennes. Since these are included in TG(B), other

Table 3
Content of Roman timber group TG(B).

DCCD series identifier	Find location	DCCD project code	Structure	Element type	First year	Last year	Felling date[a]
C4A0201Z	Leiden Voorburg	P:1988001	*Forum Hadriani*, water wells	Pile	83 BC	AD 116	In AD 227 ± 8
C4A0401_0402_1601_1602_T				Beams and planks	60 BC	AD 21	
C4A0503_0505_0801_0802_0804_T				Planks	76 BC	AD 186	
C4A0504Z				Plank	73 BC	AD 188	
C4A0601Z				Unknown	91 BC	AD 80	
C4A0901Z				Unknown	15 BC	AD 201	
C4A1301Z				Pile	109 BC	75 BC	
C4A1401_1402_T				Piles	98 BC	AD 142	
C4A1701Z				Unknown	42 BC	AD 205	
DMN10251	Utrecht De Meern	P:2004070	Ship *De Meern 1*, bed	Plank	46 BC	AD 138	After AD 164 ± 8
DMN10301		P:2004095	Ship *De Meern 1*, cabin floor	Plank	78 BC	AD 53	After AD 72 ± 6
ELT00011	Elst	P:2002110	Pallisade around temple	Pile	19 BC	AD 77	After AD 106 ± 6
ELT00030				Pile	14 BC	AD 86	
ELT00050				Pile	58 BC	AD 6	
ELT00060				Pile	37 BC	AD 84	
ELT00070				Pile	45 BC	AD 62	
ELT00080				Pile	47 BC	AD 33	
ELT00091		P:2003073		Pile	39 BC	AD 68	
ELT20021		P:2002113	*Vicus*	Pile	39 BC	AD 66	After AD 88 ± 6
ELT20031				Pile	56 BC	AD 47	
ELT20040				Pile	47 BC	AD 32	
VAL00251	Valkenburg (ZH)	P:1991032	Fortress	Pile	63 BC	AD 51	After AD 69 ± 6
VAL00331		P:1992065		Pile	AD 60	AD 196	In AD 210 ± 7
VAL00401				Pile	AD 58	AD 137	
VFH00041	Leiden Voorburg	P:2008057	*Forum Hadriani*, Harbour, quays	Pile	105 BC	AD 19	In ca. AD 205
VFH00070				Pile	94 BC	AD 128	
VFH00130				Pile	69 BC	AD 117	
VFH00150				Pile	82 BC	AD 98	
VFH00230				Pile	106 BC	AD 115	
VFH00271				Pile	106 BC	AD 186	
VFH00340				Pile	121 BC	53 BC	
VFH00350				Pile	73 BC	AD 35	
VFH00360				Pile	85 BC	AD 182	
VFH00410				Pile	95 BC	AD 178	
VFH00440				Pile	90 BC	AD 195	
VFH00470				Pile	114 BC	AD 127	
VFH00480				Pile	96 BC	AD 197	
VFH00490		P:2009062		Pile	63 BC	AD 198	
VFH00540				Pile	46 BC	AD 193	
VFH00550				Pile	93 BC	AD 166	
VFH00560				Pile	70 BC	AD 175	
VFH00600		P:2010029		Pile	108 BC	AD 186	
VFH00610				Pile	116 BC	AD 169	
VFH010_590_T		Unarchived		Pile	66 BC	AD 204	

[a] Felling dates are given in the right-hand column. The term 'in' describes an exact, sapwood-based felling date or felling-date range; the term 'after' indicates a *terminus post quem* date.

timbers in this TG must have been derived from this region as well. The geographical and chronological distribution of the material in TG(B) shows that these timbers were used along the Dutch *limes* and North-Sea coast between *c*. AD 205 and 230 (Fig. 6; Table 3).

The addition to *De Meern 1* of a bed plank and a cabin-floor plank from Ardennes oak can be interpreted against this background. Given the geographical distribution of TG(B), the planks may have been added along the Dutch *limes* or North-Sea coast

Table 4
Best matches of ungrouped ships timbers with all other data (see Table 1 plus Supplementary material).

Ship	DCCD series identifier	Series providing best match		Cross-dating statistics			Assigned growth region
		DCCD project code	DCCD series identifier	t_H	*%PV*	*n*	
De Meern 1	DMN1_BP_T	P:1992040	OSD00141	5.90	74.4	80	Not assigned
	DMN100310	2010_P13	EVKS08.33	5.42	70.9	79	TG(A)
	DMN100331	P:2008057	VFH00250	4.40	71.7	46	Not assigned
De Meern 4	DMN4_6_15_T	P:2005050	DMN40031	7.26	65.5	168	TG(A)
	DMN40022	P:2005050	DMN40101	5.40	68.2	55	TG(A)
	DMN40031	P:2005050	DMN40061	7.23	72.6	71	TG(A)
	DMN40091	P:2003082	DMN10081	6.44	81.1	53	TG(A)
	DMN40101	P:2005050	DMN40160	5.87	63.9	97	TG(A)
	DMN40140	P:2005050	DMN40051	11.2	76.0	150	TG(A)

near *Forum Hadriani*. For these two planks *terminus post quem* dates were established after AD 72 (DMN10301) and AD 164 (DMN10251) respectively (Table 3; Jansma, 2007b). Given the sapwood-based felling dates of TG(B) between *c.* AD 205 and 230, the trees from which these planks were derived may have been felled during the first decades of the 3rd century. Their presence in *De Meern 1* would then indicate that this ship still functioned early in the third century AD. However, given the limited number of absolute felling dates in TG(B) this conclusion is tentative at best.

5.4. Methodological considerations

To facilitate spatial interpretations of wood provenance, the dendrochronological reference data were grouped into four organization-level categories (see 3.2). This relatively simple model does not do justice to the complex history of settlement development during the Roman period in this region (e.g. Jansen and Fokkens, 2010; De Clercq, 2009). Therefore, although in the current study the model was a helpful tool to discern spatial patterns of wood use related to ship building, in its current form it is less suited for analyses of wood use in Roman-influenced, non-military settlements. For such analyses the classifications listed in the Supplementary material should be refined.

While comparing tree-ring patterns it proved essential to verify similarities between the series low-frequency variations in a visual manner, using graphs, since such similarities are not expressed by overall values for *t* and *%PV*. Furthermore we found that Student's *t*-values alone are not enough to identify similar provenance, since series from different regions sometimes match with high values for t_H but low values for *%PV*. We therefore recommend that in dendroprovenancing studies *%PV* is used in addition to *t*.

Dendrochronological dating and provenance studies in general involve the compilation of, and comparisons between, dated average chronologies representing single archaeological objects (i.e., a specific house, water well or ship) or sites. The assumption underlying such chronologies is that the provenance of these timbers is the same. In the current study we discarded this assumption and compared individual tree-ring series regardless of their archaeological context. Our results show that this approach is well suited for identifying TGs of which the provenance can be established. However this method has one drawback: timbers with the same provenance as a particular TG may not be selected for inclusion into this TG. This will occur when a timber contains disturbances in its growth pattern, for example resulting from defoliation (e.g. when leaves were used as fodder), injuries to the trees stem or silvicultural practices. The number of TS assigned to a TG therefore may be an underrepresentation of the actual number of timbers belonging to this group and sharing the same provenance. This means that results of this approach should be interpreted in a qualitative rather than quantitative manner: if some timbers from a specific structure belong to a TG, it is possible that other timbers from the same structure also were derived from this TG's region.

6. Conclusion

The possibilities of dendrochronology in the Low Countries have improved considerably since the development of the DCCD infrastructure (Jansma et al., 2012a; Jansma, 2013). The current study focussed on three ship wrecks from Utrecht-De Meern, situated in the centre of the Netherlands along the northern frontier of *Germania inferior*: *De Meern 1* and *4* (river barges of the Zwammerdam type) and *De Meern 6* (a punt). Previous studies using relatively small numbers of dendrochronological reference data placed their provenance in the Netherlands (Jansma, 2007a, b; Dallmeijer and Morel, 2012). However the present study, based on a much larger data collection and on comparisons between individual time series instead of average chronologies, shows that these ships were constructed in present-day Flanders. Given this unexpected result, it will be worthwhile to reassess wood provenance in the Low Countries and Flanders on a broader scale, focussing on other find groups from the Roman period and extending our efforts to other periods as well.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2014.07.019.

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Cultural Landscape Database of the European Thematic Network on Cultural Landscapes and their Ecosystems (PAN Project): http://pan.cultland.org/.
Landscape reconstruction of the western part of the Limes-zone in the Netherlands (dataset Utrecht University, Van Dinter 2013): https://easy.dans.knaw.nl, persistent identifier: urn:nbn:nl:ui:13–08qf-sf.
LANMAP2 (Alterra 2007): http://www.wageningenur.nl/en/show/The-European-landscape-map.htm.
Time Team (Channel 4), Series 13, episode 5: The boat on the Rhine, Utrecht: http://www.channel4.com/programmes/time-team/episode-guide/series-13/.